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The Effect of Adding Lime And Rice Husk Ash on The Cbr Value of Expansive Soil in The Purwodadi Area, Grobogan Regency, Central Java

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Abstract

Expansive soil from Pulorejo Village, Purwodadi District, Grobogan Regency, Central Java, exhibits high plasticity and relatively low bearing capacity, requiring stabilization before use as pavement subgrade. This study evaluated the effects of lime, rice husk ash, and their combination at 2.5%, 5%, 7.5%, and 10% on soil plasticity, compaction, and California Bearing Ratio (CBR). Laboratory testing included Atterberg limits, Modified Proctor, and CBR tests. The natural soil had a Liquid Limit of 74.02%, Plastic Limit of 32.22%, Plasticity Index of 41.80%, and CBR of 5.8%. Stabilization reduced plasticity and modified compaction characteristics. Lime increased the maximum CBR to 17.2% at 10%, while rice husk ash increased it to 15.8% at 10%. The combined lime–rice husk ash treatment produced the highest CBR of 18.5% at the 10% variation. These results indicate that the combined stabilizer provided the most effective improvement in bearing performance and offers a technically promising approach for improving expansive subgrade soil while utilizing agricultural waste as a supplementary stabilization material. The findings support sustainable soil improvement strategies for road construction in areas characterized by highly plastic expansive soils.

Keywords: *California Bearing Ratio, expansive soil, lime, rice husk ash, soil stabilization.*

INTRODUCTION

Soil is a fundamental component of civil engineering systems because it receives and transfers structural loads to the underlying ground layers, making its physical and mechanical properties critical to infrastructure performance. Geotechnical problems become more pronounced when construction is carried out on expansive soils, which undergo considerable volumetric changes in response to variations in moisture content. Repeated swelling and shrinkage may induce deformation, cracking, differential settlement, and reductions in bearing capacity, ultimately compromising the serviceability of roads and buildings (Barman & Dash, 2022). Therefore, accurate characterization of expansive soils and the development of effective stabilization techniques remain essential for ensuring the long-term performance of geotechnical structures (Zada et al., 2023).

Expansive soils are generally dominated by fine-grained particles and exhibit high plasticity, with mineralogical characteristics that are highly sensitive to fluctuations in water content. Their expansive behavior is commonly evaluated using Atterberg limits, particularly the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), which describe the consistency and plasticity range of the soil. High LL and PI values are generally associated with greater volumetric instability and a higher likelihood of deformation in subgrade layers (Maheepala et al., 2022). Consequently, expansive soils are widely regarded as problematic geomaterials that require improvement before being used as supporting layers in pavement and foundation systems (Sahoo & Singh, 2022).

Such conditions were identified in soil collected from Pulorejo Village, Purwodadi District, Grobogan Regency, Central Java, which serves as the study area in this investigation. Laboratory testing showed that the natural soil had a Liquid Limit of 74.02%, a Plastic Limit of 32.22%, and a Plasticity Index of 41.80%, indicating a highly plastic and expansive soil condition. The soil also exhibited 88.93% passing the No. 200 sieve and an initial CBR value of 5.80%, demonstrating the predominance of fine particles and relatively limited bearing capacity for subgrade applications.

These characteristics confirm the need for stabilization measures capable of reducing plasticity while simultaneously improving the mechanical performance of the soil.

Lime stabilization is one of the most widely applied chemical improvement methods for expansive soils because it can modify both the physicochemical and mechanical behavior of fine-grained soils. The addition of lime promotes cation exchange, flocculation-agglomeration, and pozzolanic reactions that generate cementitious compounds, thereby reducing plasticity and increasing soil strength (Zhou et al., 2023). Previous studies have also demonstrated that lime-based stabilization can significantly improve the engineering behavior of expansive soils intended for pavement subgrade applications (Malkawi et al., 2023). Nevertheless, the effectiveness of lime treatment depends on several factors, including soil mineralogy, stabilizer content, compaction conditions, curing environment, and the availability of reactive pozzolanic constituents.

In addition to lime, rice husk ash (RHA) has considerable potential as a soil-stabilizing material because it is an agricultural by-product rich in reactive silica. The use of RHA in geotechnical engineering not only contributes to soil improvement but also supports the beneficial reuse of biomass waste and the development of more sustainable construction practices (Blayi et al., 2025). Under alkaline conditions, silica contained in RHA may react with available calcium to form cementitious products that enhance particle bonding and improve the mechanical characteristics of stabilized soils (Pushpakumara & Mendis, 2022). Several studies have reported that RHA can improve soil strength and bearing capacity and can therefore serve as a supplementary material for subgrade stabilization (Wibowo et al., 2023; Shehata et al., 2024).

The combined use of lime and rice husk ash is particularly relevant because both materials can contribute complementary stabilization mechanisms. Lime provides calcium and creates a highly alkaline environment, whereas RHA supplies reactive silica that promotes pozzolanic reactions and the formation of binding compounds within the soil matrix (Li et al., 2024). Previous investigations have shown that lime-RHA mixtures can reduce plasticity, improve strength, and enhance the engineering properties of soils used in geotechnical and pavement applications (Noman et al., 2023; Kamba et al., 2025). However, soil response to combined stabilization varies considerably according to local material characteristics, making experimental evaluation necessary to determine an appropriate stabilizer proportion for a particular site.

The California Bearing Ratio (CBR) is one of the principal parameters used to assess the effectiveness of soil stabilization for road construction because it represents the relative resistance of a soil to penetration under controlled loading. A low CBR value generally indicates insufficient subgrade bearing capacity, whereas an increase after stabilization reflects an improvement in the mechanical performance of the treated material. CBR-based evaluations have been extensively applied to assess the effectiveness of RHA-based and other stabilization systems for expansive and weak subgrade soils (Ahmad et al., 2023; Anjum et al., 2025). Accordingly, CBR analysis should be interpreted together with plasticity and compaction characteristics to provide a more comprehensive assessment of soil improvement.

Based on these considerations, this study investigates the effects of lime, rice husk ash, and their combination on the plasticity characteristics and CBR values of expansive soil from the Purwodadi area of Grobogan Regency. Stabilizer contents of 2.5%, 5%, 7.5%, and 10% were evaluated to determine the progressive changes in soil behavior associated with increasing additive proportions. The experimental program incorporated Atterberg limit, Modified Proctor, and California Bearing Ratio tests to provide an integrated evaluation of the physical and mechanical response of the stabilized soil. The findings are expected to provide empirical evidence regarding the most effective stabilization composition while supporting the utilization of rice husk ash as an alternative material for improving expansive subgrade soils in road construction.

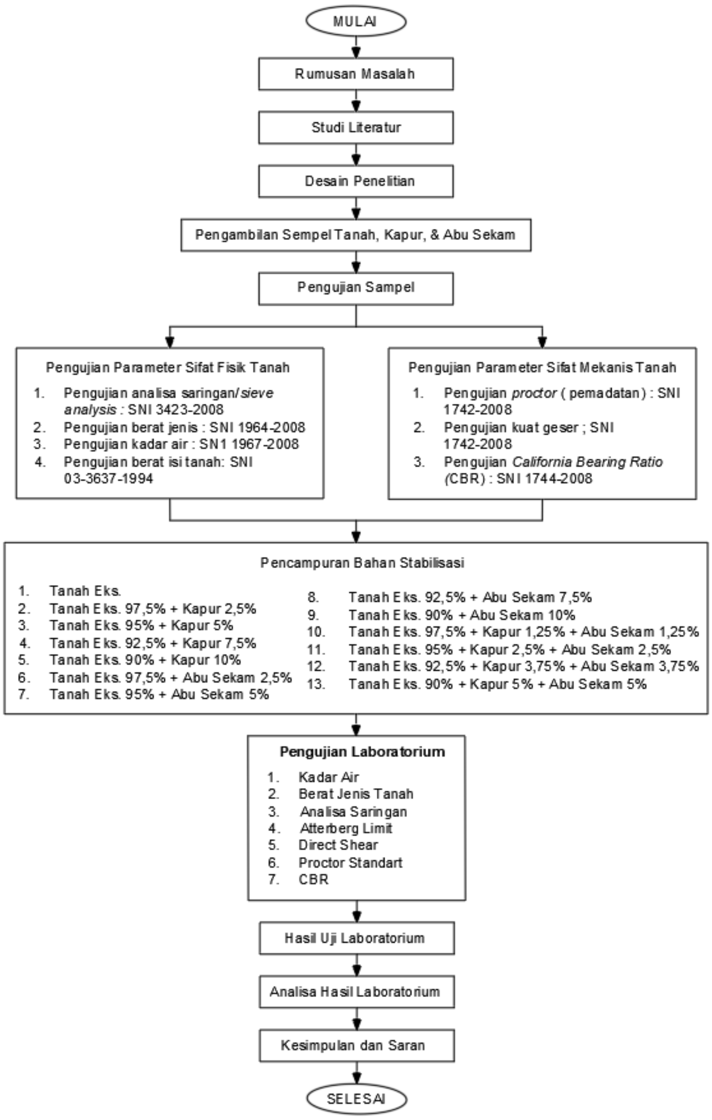
RESEARCH METHODS

This study employed an experimental laboratory design to evaluate the effects of lime, rice husk ash (RHA), and their combination on the physical and mechanical properties of expansive soil. The soil samples were collected from Pulorejo Village, Purwodadi District, Grobogan Regency, Central Java, Indonesia, and were tested in their natural condition and after stabilization. Three stabilization schemes were investigated, namely lime only, RHA only, and a combined lime–RHA mixture, with total additive contents of 2.5%, 5%, 7.5%, and 10% by dry weight of soil. For the combined mixtures, the proportions were 1.25% lime + 1.25% RHA, 2.5% lime + 2.5% RHA, 3.25% lime + 3.25% RHA, and 5% lime + 5% RHA, corresponding to total stabilizer contents of 2.5%, 5%, 7.5%, and 10%, respectively. All specimens were prepared under controlled laboratory conditions to ensure that the observed changes in soil behavior could be attributed to the type and proportion of stabilizing material.

Table 1. Specimen Mixture Variations

Variation	Soil	Lime	Rice Husk Ash	Combination
2.5%	Natural soil as the testing baseline	2.5%	2.5%	1.25% lime + 1.25% rice husk ash
5%	Natural soil as the testing baseline	5%	5%	2.5% lime + 2.5% rice husk ash
7.5%	Natural soil as the testing baseline	7.5%	7.5%	3.25% lime + 3.25% rice husk ash
10%	Natural soil as the testing baseline	10%	10%	5% lime + 5% rice husk ash

The experimental program consisted of tests on specific gravity, particle-size distribution, Atterberg limits, compaction characteristics, shear strength parameters, and California Bearing Ratio (CBR). Modified Proctor testing was conducted to determine the optimum moisture content and maximum dry density of the untreated and stabilized soils, and these compaction parameters were subsequently used in the preparation of the CBR specimens. The CBR test was then used as the principal indicator of subgrade bearing-capacity improvement, while changes in Liquid Limit, Plastic Limit, and Plasticity Index were used to evaluate the reduction in soil plasticity. The experimental results were comparatively analyzed across all mixture proportions to determine the relative effectiveness of lime, RHA, and their combination in improving the engineering performance of the expansive soil.



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RESULTS AND DISCUSSION

Characteristics and Engineering Behaviour of the Natural Expansive Soil

The initial characterization of the natural soil provides the fundamental basis for evaluating the effectiveness of the subsequent stabilization treatments. Laboratory testing showed that the soil collected from Pulorejo Village, Purwodadi District, Grobogan Regency exhibited physical and mechanical characteristics associated with fine-grained expansive soil. The measured Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) were 74.02%, 32.22%, and 41.80%, respectively, indicating a wide plastic consistency range. Such high plasticity is particularly relevant in geotechnical engineering because expansive fine-grained soils are susceptible to moisture-induced volume changes that may adversely affect pavement subgrades and shallow infrastructure (Barman & Dash, 2022; Zada et al., 2023).

Particle-size characteristics further support the identification of the tested material as a predominantly fine-grained soil. The laboratory results showed that 88.93% of the soil particles passed the No. 200 sieve, demonstrating that fine particles constituted the dominant fraction of the natural material. A high fine fraction combined with a high PI generally indicates that the engineering response of the soil is strongly governed by interactions between clay-sized particles and water rather than by granular interlocking. This condition is consistent with the behavior commonly reported for expansive soils, in which moisture sensitivity, plastic deformation, and volume instability represent major constraints for geotechnical applications (Maheepala et al., 2022; Sahoo & Singh, 2022).

The natural soil had a specific gravity (GS) of 2.683, which provides an important reference for interpreting its basic physical characteristics and for subsequent compaction calculations. Specific gravity alone does not determine expansiveness, but its interpretation together with gradation and consistency parameters enables a more comprehensive assessment of the material before stabilization. In the present case, the combination of GS = 2.683, 88.93% passing the No. 200 sieve, and PI = 41.80% confirms that the untreated soil should be evaluated primarily as a fine-grained material with substantial plastic behavior. This baseline characterization is essential because chemical stabilization reactions and the resulting strength improvement are strongly influenced by the mineralogical and physicochemical characteristics of the untreated soil (Zhou et al., 2023).

The consistency-limit results provide particularly strong evidence of the problematic nature of the natural soil. An LL of 74.02% indicates that the material remains in a plastic state over a comparatively high range of moisture contents, whereas the PL of 32.22% marks the lower boundary of this plastic condition. Their difference produces a PI of 41.80%, as reported directly by the laboratory measurements, and this value represents the magnitude of the soil's plastic range. From an engineering perspective, this level of plasticity justifies stabilization because high-plasticity expansive soils can exhibit substantial changes in consistency and mechanical performance under varying moisture conditions (Malkawi et al., 2023; Soltani et al., 2022).

The compaction characteristics of the untreated soil also provide a critical reference condition for evaluating the stabilized specimens. The natural soil exhibited an optimum moisture content (WoptW_{opt}) of 29.00%, while the maximum dry unit weight (γd\gamma_d max) recorded in the original dataset was 1.07 kN/m^3. The relatively high optimum moisture requirement is compatible with the substantial fine fraction and plastic behavior observed in the material, because fine-grained soils generally require water to facilitate particle rearrangement during compaction. These untreated compaction parameters therefore establish the baseline against which changes induced by lime, rice husk ash, and their combined application can subsequently be evaluated (Pushpakumara & Mendis, 2022).

Table 2. Test Results of the Natural Soil

No.	Property	Value	Unit
1	Specific Gravity (GS)	2.683	–
2	Soil particles passing No. 200 sieve	88.93	%
3	Optimum Moisture Content (WoptW_{opt})	29.00	%
4	Maximum Dry Unit Weight (γd\gamma_d Max)	1.07	kN/m^3
5	Liquid Limit (LL)	74.02	%
6	Plastic Limit (PL)	32.22	%
7	Plasticity Index (PI)	41.80	%
8	Cohesion (c)	0.347	kg/cm^2
9	Internal Friction Angle (φ)	23.13	°
10	CBR Value	5.80	%

Note: All numerical values and units are retained exactly from the original dataset; only the property descriptions have been translated into English.

The shear-strength parameters further characterize the mechanical condition of the untreated soil, with a cohesion value of 0.347 kg/cm^2 and an internal friction angle of 23.13°. These parameters indicate that the resistance of the soil to shearing is governed by both cohesive interaction and frictional resistance, although their practical contribution may change markedly as moisture conditions vary. For expansive fine-grained soils, moisture sensitivity can alter interparticle forces and consequently affect the mobilized shear resistance under field conditions. The observed baseline shear-strength characteristics therefore provide additional evidence for evaluating whether chemical or pozzolanic stabilization can create a denser and more strongly bonded soil matrix (Sahoo & Singh, 2022; Zhou et al., 2023).

Of particular importance for pavement applications, the untreated soil produced a California Bearing Ratio of only 5.80%. The CBR represents the penetration resistance of the soil and is widely used to assess the mechanical suitability of subgrade materials, meaning that the value obtained for the natural soil establishes a direct performance benchmark for all subsequent stabilized specimens. The combination of a CBR of 5.80% and a PI of 41.80% demonstrates that the principal engineering concern is not limited to plasticity but also extends to the relatively weak bearing response of the untreated material. Similar research has consequently emphasized the importance of increasing CBR when evaluating stabilization strategies for expansive soil intended for pavement construction (Ahmad et al., 2023).

The relationship among the measured parameters is more informative than interpretation of any single index in isolation. The 88.93% fraction passing the No. 200 sieve confirms the dominance of fine particles, while LL = 74.02% and PI = 41.80% demonstrate high consistency and plasticity, and the CBR value of 5.80% indicates limited penetration resistance in the untreated state. This combination describes a material whose engineering behavior is highly dependent on moisture and whose bearing characteristics require improvement before more reliable subgrade performance can be expected. Such multidimensional characterization is consistent with current approaches to expansive-soil stabilization, which evaluate physical indices, compaction behavior, and mechanical resistance together rather than relying exclusively on one parameter (Barman & Dash, 2022; Zada et al., 2023).

The baseline condition also provides an appropriate reference for identifying the magnitude of improvement attributable to the stabilizing agents in the subsequent tests. Any reduction in LL or PI after treatment can be interpreted relative to the initial values of 74.02% and 41.80%, while changes in optimum moisture content and maximum dry unit weight can be assessed relative to 29.00% and 1.07 kN/m³, respectively. Likewise, the original CBR value of 5.80% serves as the control against which the bearing-capacity improvement generated by each lime, RHA, and lime–RHA mixture can be quantified without altering the experimental data. The use of an untreated control is particularly important in RHA–lime stabilization research because the engineering benefit of pozzolanic treatment must be demonstrated through measurable changes relative to the original soil condition (Pushpakumara & Mendis, 2022; Raja et al., 2022).

Overall, the natural soil from Pulorejo can be characterized as a highly plastic, fine-grained expansive soil with limited initial bearing performance. The experimental values demonstrate that the material simultaneously exhibits a high percentage of fines, a wide plasticity range, considerable optimum moisture demand, and a relatively low CBR, thereby providing a technically justified basis for stabilization. These properties also establish a coherent baseline for evaluating whether lime and rice husk ash can modify soil consistency, compaction behavior, and load-bearing response through physicochemical and pozzolanic mechanisms. Consequently, the untreated-soil results support the subsequent comparative analysis of the individual and combined stabilizers, particularly in determining whether the treatments can reduce plasticity and increase CBR to a greater extent than the natural condition (Ahmad et al., 2023; Barman & Dash, 2022).

Effect of Lime and Rice Husk Ash Stabilization on Plasticity and Compaction Characteristics

The stabilization treatments produced a clear modification in the consistency behavior of the expansive soil. The original manuscript reports that the addition of lime, rice husk ash (RHA), and their combination reduced the Liquid Limit, Plastic Limit, and Plasticity Index compared with the untreated soil, indicating a reduction in overall plasticity and moisture sensitivity. This trend is consistent with the general behavior of chemically stabilized expansive soils, in which additive-induced physicochemical reactions alter clay-particle interactions and reduce susceptibility to volumetric change (Barman & Dash, 2022; Zada et al., 2023). The reduction in plasticity is particularly important for subgrade applications because lower plasticity generally contributes to improved dimensional stability under changing moisture conditions.

The influence of lime can be associated with short-term cation exchange and flocculation-agglomeration processes, followed by longer-term pozzolanic reactions. These mechanisms reduce the thickness of the diffuse double layer around clay particles, promote aggregation, and gradually form cementitious compounds that improve the structural integrity of the stabilized matrix (Zhou et al., 2023). Similar improvements have been reported for expansive soils treated with lime-based binders, particularly where stabilization is intended to improve pavement subgrade performance

(Malkawi et al., 2023; Efamo & Adera, 2024). Therefore, the observed decline in soil plasticity after lime addition is consistent with the expected physicochemical transformation of highly plastic clay.

Rice husk ash contributes through a different but complementary mechanism because its silica-rich composition provides reactive material for pozzolanic bonding. Previous studies have demonstrated that RHA can improve the engineering behavior of weak and expansive soils when sufficient calcium or alkaline activation is available (Pushpakumara & Mendis, 2022; Ayodele et al., 2022). The use of RHA is also attractive from a sustainability perspective because it converts an agricultural residue into a functional geotechnical material, thereby reducing dependence on conventional binders and supporting waste valorization (Blayi et al., 2025; Naik et al., 2024). Its contribution in the present study is therefore relevant both mechanically and environmentally.

The combined lime–RHA treatment is particularly significant because the two additives can interact synergistically. Lime provides calcium and a highly alkaline medium, while RHA contributes reactive silica that can participate in the formation of calcium-silicate-based binding products (Li et al., 2024). Similar combined-material approaches have been reported to improve soil strength, stiffness, durability, and subgrade performance when agricultural ash is incorporated into stabilization systems (Reis et al., 2022; Anburuvel et al., 2023). Consequently, the reduction in plasticity reported in the present study can reasonably be interpreted as an indication of progressive modification of the soil fabric rather than merely physical dilution of the clay fraction.

In addition to consistency changes, the Modified Proctor test provides a more direct indication of how stabilization altered the compaction behavior of the soil. The original soil had an optimum moisture content of 29.00%, whereas all stabilized specimens exhibited different moisture-density relationships depending on the type and percentage of additive. The original dataset shows that the stabilized mixtures generally required lower optimum moisture contents than the untreated soil, although the magnitude and direction of dry-density change varied among lime, RHA, and combined treatments. These differences indicate that the additives modified particle arrangement, water demand, and compaction efficiency, which are central considerations in stabilized subgrade design (Mostafa et al., 2024; Wibowo et al., 2023).

Table 3. Modified Proctor Test Results of Natural and Stabilized Soils

No.	Sample	Wopt (%)	γd 100% (gr/cm³)
1	Natural Soil	29.00	1.32
2	Soil + 2.5% Lime	23.40	1.33
3	Soil + 5% Lime	22.80	1.35
4	Soil + 7.5% Lime	22.00	1.361
5	Soil + 10% Lime	21.70	1.39
6	Soil + 2.5% Rice Husk Ash	24.10	1.30
7	Soil + 5% Rice Husk Ash	23.70	1.31
8	Soil + 7.5% Rice Husk Ash	23.20	1.33
9	Soil + 10% Rice Husk Ash	23.00	1.352
10	Soil + Lime & Rice Husk Ash 2.5%	22.65	1.39
11	Soil + Lime & Rice Husk Ash 5%	23.10	1.36
12	Soil + Lime & Rice Husk Ash 7.5%	23.90	1.33
13	Soil + Lime & Rice Husk Ash 10%	25.00	1.31

Note: All numerical values are reproduced exactly from the original dataset and have not been modified.

For the lime-treated specimens, increasing lime content from 2.5% to 10% progressively reduced the optimum moisture content from 23.40% to 21.70%. At the same time, the reported dry-density value increased from 1.33 gr/cm³ at 2.5% lime to 1.39 gr/cm³ at 10% lime, compared with 1.32 gr/cm³ for the natural soil. This progressive pattern indicates that lime substantially altered the compaction response and enabled a denser stabilized structure at the higher percentages tested. Comparable changes in compaction and mechanical behavior have been reported in lime-based stabilization of expansive subgrades, although the magnitude of the response remains dependent on soil mineralogy and treatment conditions (Sambre et al., 2024; Soltani et al., 2022).

The RHA-treated series showed a different but similarly systematic response. Optimum moisture content decreased from 24.10% at 2.5% RHA to 23.00% at 10% RHA, while the corresponding dry-density values increased from 1.30 to 1.352 gr/cm³. Although the dry density at the lower RHA content was slightly below that of the untreated soil, the value increased as the RHA proportion increased, suggesting that the compaction characteristics evolved progressively with additive content. Similar studies have demonstrated that RHA-based treatments can modify the moisture-density relationship of subgrade soils while simultaneously contributing to strength development through silica-rich reaction products (Shehata et al., 2024; Anjum et al., 2025).

The combined lime–RHA series exhibited a more complex moisture-density pattern than the individual additives. At a total mixture level of 2.5%, the optimum moisture content was 22.65% and the dry-density value reached 1.39 gr/cm³, whereas at 10% combined additive the corresponding values were 25.00% and 1.31 gr/cm³. The intermediate mixtures produced values of 23.10% and 1.36 gr/cm³ at 5%, and 23.90% and 1.33 gr/cm³ at 7.5%, demonstrating that the combined system did not follow the same monotonic density trend as the lime-only treatment. Such behavior is plausible in multicomponent stabilization because ash content, binder reaction, particle replacement, and water demand can interact differently as mixture proportions increase (Maheepala et al., 2023; Maheepala et al., 2024).

Comparison among the three stabilization schemes shows that additive type significantly influenced compaction response. The lime-only mixtures progressively reduced optimum moisture content while increasing dry density, whereas the RHA-only mixtures showed more moderate changes and the combined mixtures exhibited a non-linear response across the tested percentages. These distinctions demonstrate that the optimum stabilizer cannot be identified solely from dry density or moisture content because compaction results must be interpreted together with plasticity and strength parameters. Recent geotechnical studies similarly emphasize integrated evaluation of compaction, strength, durability, and environmental performance when assessing alternative stabilizers for expansive soils (Maheepala et al., 2025; Maheepala et al., 2026).

Overall, the second-stage results demonstrate that lime, RHA, and lime–RHA stabilization modified both the plastic consistency and compaction behavior of the expansive soil from Purwodadi. The reported reduction in LL, PL, and PI indicates diminished plasticity, while the Modified Proctor results confirm substantial changes in optimum moisture demand and dry-density characteristics relative to the untreated condition. Because the original manuscript does not provide separate numerical post-stabilization Atterberg-limit values, the plasticity discussion is intentionally restricted to the directional reductions explicitly reported in the source rather than introducing unverified numerical values. These findings provide the necessary physical basis for the subsequent CBR analysis, in which the practical effect of the treatments on subgrade bearing capacity can be quantitatively compared.

Effect of Lime and Rice Husk Ash Stabilization on CBR and Subgrade Bearing Performance

The California Bearing Ratio results provide the clearest quantitative indication of the improvement in bearing performance generated by the stabilization treatments. The untreated expansive soil exhibited a CBR value of only 5.8%, whereas every lime, rice husk ash (RHA), and combined lime–RHA treatment produced a higher CBR value across the tested additive contents of 2.5%, 5%, 7.5%, and 10%. The consistent increase indicates that the additives modified the mechanical response of the soil and increased its resistance to penetration under the laboratory testing conditions. This pattern is consistent with previous research demonstrating that chemical and pozzolanic stabilization can significantly improve the bearing capacity of expansive and weak subgrade soils (Ahmad et al., 2023; Barman & Dash, 2022).

The lime-treated specimens exhibited a progressive increase in CBR as the lime proportion increased. The CBR increased from 5.8% for the natural soil to 11.4%, 13.3%, 14.8%, and 17.2% at lime contents of 2.5%, 5%, 7.5%, and 10%, respectively. Relative to the untreated soil, these values correspond to calculated increases of approximately 96.55%, 129.31%, 155.17%, and 196.55%, demonstrating a strong dosage-dependent improvement in bearing resistance. The increase is consistent with lime-induced flocculation, aggregation, and subsequent pozzolanic bonding that enhance the stiffness and load-transfer characteristics of expansive soil (Zhou et al., 2023; Malkawi et al., 2023).

Rice husk ash also generated a systematic improvement in the CBR response, although the values remained slightly below those obtained with lime at equivalent additive percentages. The CBR values were 11.1%, 12.8%, 13.7%, and 15.8% at RHA contents of 2.5%, 5%, 7.5%, and 10%, respectively, corresponding to calculated improvements of approximately 91.38%, 120.69%, 136.21%, and 172.41% relative to the untreated soil. The progressive increase indicates that RHA contributed positively to the mechanical performance of the subgrade despite its different physicochemical role compared with lime. This result is compatible with findings that silica-rich RHA can improve soil strength and bearing performance through particle modification and pozzolanic activity when appropriate reactive constituents are available (Ayodele et al., 2022; Wibowo et al., 2023; Shehata et al., 2024).

The combined lime–RHA treatment produced the highest CBR values among the three stabilization schemes at every tested percentage. CBR values of 12.7%, 13.95%, 16.1%, and 18.5% were obtained for combined additive contents of 2.5%, 5%, 7.5%, and 10%, respectively, while the maximum value of 18.5% occurred at the 10% combined treatment. Compared with the natural-soil CBR of 5.8%, the maximum result represents a calculated increase of approximately 218.97%, or approximately 3.19 times the initial value. The superior response of the combined treatment supports the concept that calcium supplied by lime and reactive silica supplied by RHA can act complementarily in improving the engineering behavior of stabilized soils (Pushpakumara & Mendis, 2022; Noman et al., 2023; Kamba et al., 2025).

A direct comparison at equivalent additive contents further demonstrates the advantage of combining lime and RHA. At 2.5%, the combined mixture produced a CBR of 12.7%, compared with 11.4% for lime and 11.1% for RHA; at 5%, the corresponding values were 13.95%, 13.3%, and 12.8%. At 7.5%, the combined mixture reached 16.1%, compared with 14.8% for lime and 13.7% for RHA, while at 10% the combined treatment reached 18.5%, compared with 17.2% and 15.8%, respectively. These results confirm that the combined stabilizer consistently provided the greatest penetration resistance within the range examined and demonstrate that additive interaction was more effective than either treatment used individually (Li et al., 2024; Reis et al., 2022).

Table 4. Comparison of Main CBR Values

Mixture Type	Mixture Variation	CBR Value (%)
Natural soil	–	5.8
97.5% Soil + 2.5% Lime	2.5%	11.4
95% Soil + 5% Lime	5%	13.3
92.5% Soil + 7.5% Lime	7.5%	14.8
90% Soil + 10% Lime	10%	17.2
97.5% Soil + 2.5% Rice Husk Ash	2.5%	11.1
95% Soil + 5% Rice Husk Ash	5%	12.8
92.5% Soil + 7.5% Rice Husk Ash	7.5%	13.7
90% Soil + 10% Rice Husk Ash	10%	15.8
97.5% Soil + Lime + Rice Husk Ash 2.5%	2.5%	12.7
95% Soil + Lime + Rice Husk Ash 5%	5%	13.95
92.5% Soil + Lime + Rice Husk Ash 7.5%	7.5%	16.1
90% Soil + Lime + Rice Husk Ash 10%	10%	18.5

Note: All numerical values are reproduced exactly from the original experimental dataset and have not been modified.

The magnitude of improvement is also apparent when the combined-treatment values are compared directly with those obtained from the individual stabilizers. At 2.5%, the combined CBR was approximately 11.40% higher than the lime-only result and 14.41% higher than the RHA-only result, while at 10% the corresponding advantages were approximately 7.56% and 17.09%. These calculated differences demonstrate that the superiority of the combined system was sustained across the full experimental range rather than emerging only at the highest additive level. Similar multicomponent stabilization studies have shown that the interaction of calcium-bearing and silica-bearing materials can improve soil performance beyond that achieved by a single stabilizer (Anburuvel et al., 2023; Moallemi et al., 2025).

The observed CBR development can be explained through the interaction between short-term soil modification and longer-term cementitious bonding mechanisms. Lime promotes cation exchange and flocculation of clay particles, while the silica-rich fraction of RHA can participate in pozzolanic reactions that generate additional cementitious products and strengthen interparticle bonds. The combined mechanism can produce a more stable soil skeleton capable of resisting penetration and redistributing applied stresses more effectively than the untreated material. This interpretation agrees with microscopic and mechanical investigations of lime-modified and RHA-containing soils that attribute strength development to particle restructuring and progressive formation of bonded reaction products (Li et al., 2024; Zhou et al., 2023; Kamba et al., 2025).

The present findings are also consistent with recent studies employing CBR and related mechanical indicators to evaluate sustainable soil stabilization. Ahmad et al. (2023) demonstrated that RHA-based treatment of expansive soils can produce substantial variations in CBR and that the response can be predicted from treatment parameters, while Anjum et al. (2025) reported improved subgrade performance through the use of calcium-rich residue and RHA. Moallemi et al. (2025) similarly identified significant interactions between calcium-bearing stabilizers and RHA in the optimization of expansive-soil performance, whereas Sharma et al. (2026) showed that RHA treatment can substantially modify the mechanical behavior of expansive subgrade soil. These studies support the experimental trend obtained in Purwodadi and reinforce the relevance of combining calcium-rich and silica-rich materials for subgrade improvement.

From an engineering perspective, the increase from an untreated CBR of 5.8% to a maximum value of 18.5% represents a substantial enhancement in the laboratory bearing response of the soil. The results suggest that stabilization can improve the suitability of the expansive soil for use as a subgrade material, although practical implementation should also consider field compaction, moisture variation, curing conditions, durability, additive availability, and construction quality control. The use of RHA additionally introduces a resource-efficiency benefit because agricultural waste can be incorporated into geotechnical construction rather than being treated solely as a disposal material (Blayi et al., 2025; Naik et al., 2024). Broader evaluations of stabilized subgrades likewise emphasize that mechanical performance should be considered together with durability and environmental implications when selecting an appropriate stabilization strategy (Maheepala et al., 2025; Maheepala et al., 2026).

The CBR results establish a consistent relationship between stabilizer addition and improved bearing capacity in the tested expansive soil. Lime increased the maximum CBR to 17.2%, RHA increased it to 15.8%, and their combined application produced the highest value of 18.5% at the 10% variation, confirming the combined treatment as the most effective configuration within the experimental range. The progressive increase from 2.5% to 10% also demonstrates that the improvement was maintained across increasing additive contents rather than being restricted to a single isolated mixture. Taken together with the reductions in plasticity and the changes in compaction characteristics discussed in the preceding subsections, these results demonstrate that lime–RHA stabilization provides the strongest overall improvement in the engineering performance of the expansive soil investigated in this study (Sambre et al., 2024; Mostafa et al., 2024; Raja et al., 2022).

CONCLUSION

The natural soil from Pulorejo Village, Purwodadi District, Grobogan Regency, Central Java, was identified as highly plastic expansive soil, with a Liquid Limit of 74.02%, Plastic Limit of 32.22%, Plasticity Index of 41.80%, and an initial CBR value of 5.8%. The addition of lime, rice husk ash, and their combination modified the plasticity and compaction characteristics of the soil and consistently increased its bearing capacity. The CBR value increased progressively with increasing stabilizer content, demonstrating that the applied materials were effective in improving the mechanical performance of the expansive soil.

Among the tested treatments, the 10% lime mixture produced a CBR of 17.2%, while the 10% rice husk ash mixture produced 15.8%. The combined lime–rice husk ash treatment showed the best performance, reaching a maximum CBR of 18.5% at the 10% variation. These findings indicate that the combined use of lime and rice husk ash is more effective than the individual use of either material within the investigated range and has potential as an alternative stabilization method for improving expansive soil used as pavement subgrade.

REFERENCES

Abdul Rachman Saleh Fuad Harwadi. (2017). Stabilitasi Tanah Lempung Lunak Dengan Abu Sekam Padi (RHA) dan Kapur (CaCO3) di Kampung Satu Kota Tarakan

Ahmad, M., Al-Zubi, M. A., Kubińska-Jabcoń, E., Majdi, A., Al-Mansob, R. A., Sabri, M. M. S., Ali, E., Naji, J. A., Elnaggar, A. Y., & Zamin, B. (2023). Predicting California bearing ratio of HARHA-treated expansive soils using Gaussian process regression. *Scientific Reports, 13*, 13593. https://doi.org/10.1038/s41598-023-40903-1

American Association of State Highway and Transportation Official (AASHTO). (1945).

Anburuvel, A., Sathiparan, N., Dhananjaya, G. M. A., & Anuruththan, A. (2023). Characteristic evaluation of geopolymer based lateritic soil stabilization enriched with eggshell ash and rice husk ash for road construction: An experimental investigation. *Construction and Building Materials, 387*, 131659. https://doi.org/10.1016/j.conbuildmat.2023.131659

Anjum, S., Sharma, A., Onyelowe, K. C., Alsabhan, A. H., Alam, S., Singh, K., Tiwary, A. K., Sharma, S., & Qadri, J. (2025). Sustainable subgrade improvement with calcium carbide residue and rice husk ash. *Scientific Reports, 15*, 14351. https://doi.org/10.1038/s41598-025-98833-z

Arlyn Aristo Cikmit, Rangga Adiprima Sudisman, Wirman Hidayat, Bagus Guritno, Muhammad Brianjaya Andhika. (2024). Studi Pengaruh Batas Atterberg Terhadap Kuat Geser Tanah Ekspansif dan Non Ekspansif.

Ayodele, F. O., Fajimi, M. S., & Alo, B. A. (2022). Stabilization of tropical soil using calcium carbide residue and rice husk ash. *Materials Today: Proceedings, 60*(1), 216–222. https://doi.org/10.1016/j.matpr.2021.12.465

Barman, D., & Dash, S. K. (2022). Stabilization of expansive soils using chemical additives: A review. *Journal of Rock Mechanics and Geotechnical Engineering, 14*(4), 1319–1342. https://doi.org/10.1016/j.jrmge.2022.02.011

Begeman. (1965). Konsistensi Tanah.

Blayi, R. A., Kakrasul, J. I., & Hamad, S. M. (2025). An overview of rice husk ash as a waste by-product material for sustainable soil stabilization. *Cleaner Waste Systems, 12*, 100446. https://doi.org/10.1016/j.clwas.2025.100446

Bowles, J. E. (1987). Physical and Geotechnical Properties of Soils. Bowles, J. E. (1994). Foundation Analysis and Design.

Chen,F.H., 1975, Foundation on Expansive Soils. Elsevier Scientific Publishing Company, New York.

Coduto, D. P. (1994). Foundation Design: Principles and Practices. Das, B. M. (1985). Principles of Geotechnical Engineering.

Das, B. M. (1993). Soil Mechanics.

Das, B. M. (1995). Advanced Soil Mechanics.

Denny Boy Pinasang, dkk. (2016). Analisis Campuran Kapur-Fly Ash dan Kapur-Abu Sekam Padi Terhadap Lempung Ekspansif.

Efamo, A. B., & Adera, B. (2024). Study on the effect of cinder ash as an auxiliary additive mineral in hydrated lime treatment for expansive sub-grade soil in road construction. *Discover Civil Engineering, 1*, 105. https://doi.org/10.1007/s44290-024-00111-w

Hardiyatmo, H. C. (1992). Mekanika Tanah 1.

Hardiyatmo, H. C. (2002). Mekanika Tanah 2.

I Nyoman Aribudiman. (). Karakteristik Tanah Lempung Ekspansif Yang Ditambahkan Semen Dan Abu Sekam Padi Sebagai Subgrade Jalan.

John Tri Hatmoko. (2007). UCS Tanah Lempung Ekspansif Yang Distabilisasi Dengan Abu Ampas Tebu dan Kapur. Skripsi. Yogyakarta.

Kamba, A., Nakamoga, P., Kiwanuka, M., & Niyomukiza, J. B. (2025). Sustainable stabilization of expansive soil using rice husk ash, sisal fiber, and lime. *Jurnal Presipitasi: Media Komunikasi* *dan Pengembangan Teknik Lingkungan, 22*(3), 1002–1014. https://doi.org/10.14710/presipitasi.v22i3.1002-1014

Li, N., Yu, S., Wu, E., Song, X., Jiang, P., Xu, H., & Wang, W. (2024). Study on small strain characteristics and microscopic mechanism of rice husk ash modified lime soil. *Transportation Geotechnics, 45*, 101209. https://doi.org/10.1016/j.trgeo.2024.101209

Maheepala, M. M. A. L. N., Nasvi, M. C. M., Robert, D. J., Gunasekara, C., & Kurukulasuriya, L. C. (2022). A comprehensive review on geotechnical properties of alkali activated binder treated expansive soil. *Journal of Cleaner Production, 363*, 132488. https://doi.org/10.1016/j.jclepro.2022.132488

Maheepala, M. M. A. L. N., Nasvi, M. C. M., Robert, D. J., Gunasekara, C., & Kurukulasuriya, L. C. (2023). Mix design development for geopolymer treated expansive subgrades using artificial neural network. *Computers and Geotechnics, 161*, 105534. https://doi.org/10.1016/j.compgeo.2023.105534

Maheepala, M. M. A. L. N., Nasvi, M. C. M., Robert, D. J., Gunasekara, C., & Kurukulasuriya, L. C. (2024). Mix optimization for expansive soil stabilized with a novel waste material-based geopolymerization approach. *Canadian Geotechnical Journal, 61*(10), 2180–2205. https://doi.org/10.1139/cgj-2023-0271

Maheepala, M. M. A. L. N., Nasvi, M. C. M., Robert, D. J., Kurukulasuriya, L. C., & Gunasekara, C. (2025). Life-cycle assessment of novel geopolymer stabilization method in applications with expansive subgrades. *Transportation Research Part D: Transport and Environment, 146*, 104840. https://doi.org/10.1016/j.trd.2025.104840

Maheepala, M. M. A. L. N., Nasvi, M. C. M., Robert, D. J., Kurukulasuriya, L. C., Gunasekara, C., & Nimesha, K. M. D. (2026). Durability performance of geopolymer stabilised expansive soil incorporating novel rice husk ash-based waste derived alkaline activator. *International Journal of Pavement Engineering, 27*(1), 2642959. https://doi.org/10.1080/10298436.2026.2642959

Malkawi, D. A., Rabab'ah, S. R., AlSyouf, M. M., & Aldeeky, H. (2023). Utilizing expansive soil treated with phosphogypsum and lime in pavement construction. *Results in Engineering, 19*, 101256. https://doi.org/10.1016/j.rineng.2023.101256

Moallemi, M., Dehnad, M. H., & Khodaparast, M. (2025). Statistical analysis of expansive soil stabilized with calcium carbide residue and rice husk ash using response surface methodology. *Advances in Civil Engineering, 2025*, 8871435. https://doi.org/10.1155/adce/8871435

Mostafa, A. E. A., Eisa, M., & Ibrahim, M. F. (2024). Effect of stabilizing subgrade layer using various additives on the flexible pavement design. *Innovative Infrastructure Solutions, 9*, 147. https://doi.org/10.1007/s41062-024-01430-8

Muhamad Zidan Algipari, Yanyan Agustian. (2026). Pengaruh Penambahan Abu Sekam Padi pada Stabilitas Tanah Ditinjau dari Nilai California Bearing Ratio (Studi Kasus: Desa Legoksari)

Muhammad Irfan Alfaros, Zaidan Kamil. Perbaikan Tanah Lempung Lunak dengan Penambahan Fly Ash dan Bottom Ash. Laporan Tugas Akhir.

Naik, R., Kumar, S., & Saha, G. (2024). Novel framework for assessing economic viability and environmental impacts: Use of waste products in soil stabilization. *Construction and Building Materials, 411*, 134329. https://doi.org/10.1016/j.conbuildmat.2023.134329

Noman, A. A., Raton, M., & Rahman, K. (2023). The application of rice husk ash and lime as a stabilizer for constriction purposes. *Geotechnical Engineering Journal of the SEAGS & AGSSEA, 54*(1), 41–45. https://doi.org/10.14456/seagj.2023.25

Pushpakumara, B. H. J., & Mendis, W. S. W. (2022). Suitability of rice husk ash (RHA) with lime as a soil stabilizer in geotechnical applications. *International Journal of Geo-Engineering, 13*, 4. https://doi.org/10.1186/s40703-021-00169-w

Raja, K., Venkatachalam, S., Vishnuvardhan, K., Siva Rama Krishnan, R., Tamil Selvan, V., & Vetriselvan, N. (2022). A review on soil stabilization using rice husk ash and lime sludge. *Materials Today: Proceedings, 65*(2), 1205–1212. https://doi.org/10.1016/j.matpr.2022.04.178

Reis, J. B., Pelisser, G., Levandoski, W. M. K., Ferrazzo, S. T., Mota, J. D., Silveira, A. A., & Korf, E. P. (2022). Experimental investigation of binder based on rice husk ash and eggshell lime on soil stabilization under acidic attack. *Scientific Reports, 12*, 7542. https://doi.org/10.1038/s41598-022-11529-6

.

Sahoo, S., & Singh, S. P. (2022). Strength and durability properties of expansive soil treated with geopolymer and conventional stabilizers. *Construction and Building Materials, 328*, 127078. https://doi.org/10.1016/j.conbuildmat.2022.127078

Sambre, T., Endait, M., & Patil, S. (2024). Sustainable soil stabilization of expansive soil subgrades through lime-fly ash admixture. *Discover Civil Engineering, 1*, 65. https://doi.org/10.1007/s44290-024-00063-1

Sharma, A., Singh, K., Senagah, A., Sidhu, N., Tiwary, A. K., Juneja, G., Verma, S. K., Gupta, R., & Joia, P. S. (2026). Performance-based evaluation and UCS prediction of rice husk ash-stabilized expansive subgrade soil using experiments and explainable machine learning. *Multiscale and Multidisciplinary Modeling, Experiments and Design, 9*, 150. https://doi.org/10.1007/s41939-026-01233-7

Shehata, A. A. A., Owino, A. O., Islam, M. Y., & Hossain, Z. (2024). Shear strength of soil by using rice husk ash waste for sustainable ground improvement. *Discover Sustainability, 5*, 64. https://doi.org/10.1007/s43621-024-00238-x

Sipilpedia. (2017). Mortar Busa sebagai Material Timbunan Ringan.

Skempton, A.W., 1953, The Colloid Activity of Clays, Procc of The 3th International Conference of Soil Mechanics and Foundation Engineering. Zurtch.

SNI 03-1964-2008. Metode Pengujian Berat Jenis Tanah.

SNI 03-1967-2008. Metode Pengujian Batas Atterberg.

SNI 03-3420-2016. Metode Pengujian Kuat Geser Tanah dengan Alat Geser Langsung (Direct Shear Test).

SNI 03-3423-2008. Metode Pengujian Analisis Ukuran Butiran Tanah dengan Hidrometer.

SNI 03-3637-1994. Metode Pengujian Berat Isi Tanah. SNI 1742-2008. Metode Pengujian Proctor Standard.

SNI 1743-2008. Metode Pengujian Proctor Modified. SNI 1744-2012. Metode Pengujian CBR Laboratorium.

Soltani, A., Taheri, A., Deng, A., & O'Kelly, B. C. (2022). Stabilization of a highly expansive soil using waste-tire-derived aggregates and lime treatment. *Case Studies in Construction Materials, 16*, e01133. https://doi.org/10.1016/j.cscm.2022.e01133

Syawal, dkk. (2016). Dampak Penambahan Kapur Pada Tanah Lempung Ekspansif Terhadap Nilai CBR Tanah Dasar Konstruksi Jalan.

Wibowo, D. E., Ramadhan, D. A., Endaryanta, & Prayuda, H. (2023). Soil stabilization using rice husk ash and cement for pavement subgrade materials. *Revista de la Construcción, 22*(1), 192–202. https://doi.org/10.7764/RDLC.22.1.192

Widhiarto, H., Andriawan, A.H., & Matulessy, A., 2015., Stabilisasi Tanah Lempung Ekspansif dengan Menggunakan Campuran Abu-Sekam dan Kapur, Jurnal Pengabdian LPPM Untag, Surabaya..

Zada, U., Jamal, A., Iqbal, M., Eldin, S. M., Almoshaogeh, M., Bekkouche, S. R., & Almuaythir, S. (2023). Recent advances in expansive soil stabilization using admixtures: Current challenges and opportunities. *Case Studies in Construction Materials, 18*, e01985. https://doi.org/10.1016/j.cscm.2023.e01985

Zhou, A., Du, J., Lin, X., Bu, Y., & Kodikara, J. (2023). Nanoscale mechanism on lime stabilization of expansive soil. *Acta Geotechnica, 18*(5), 2681–2701. https://doi.org/10.1007/s11440-022-01751-x